Nitrogen oxide emissions from lightning: Global source rate and tropical/mid-latitude differences

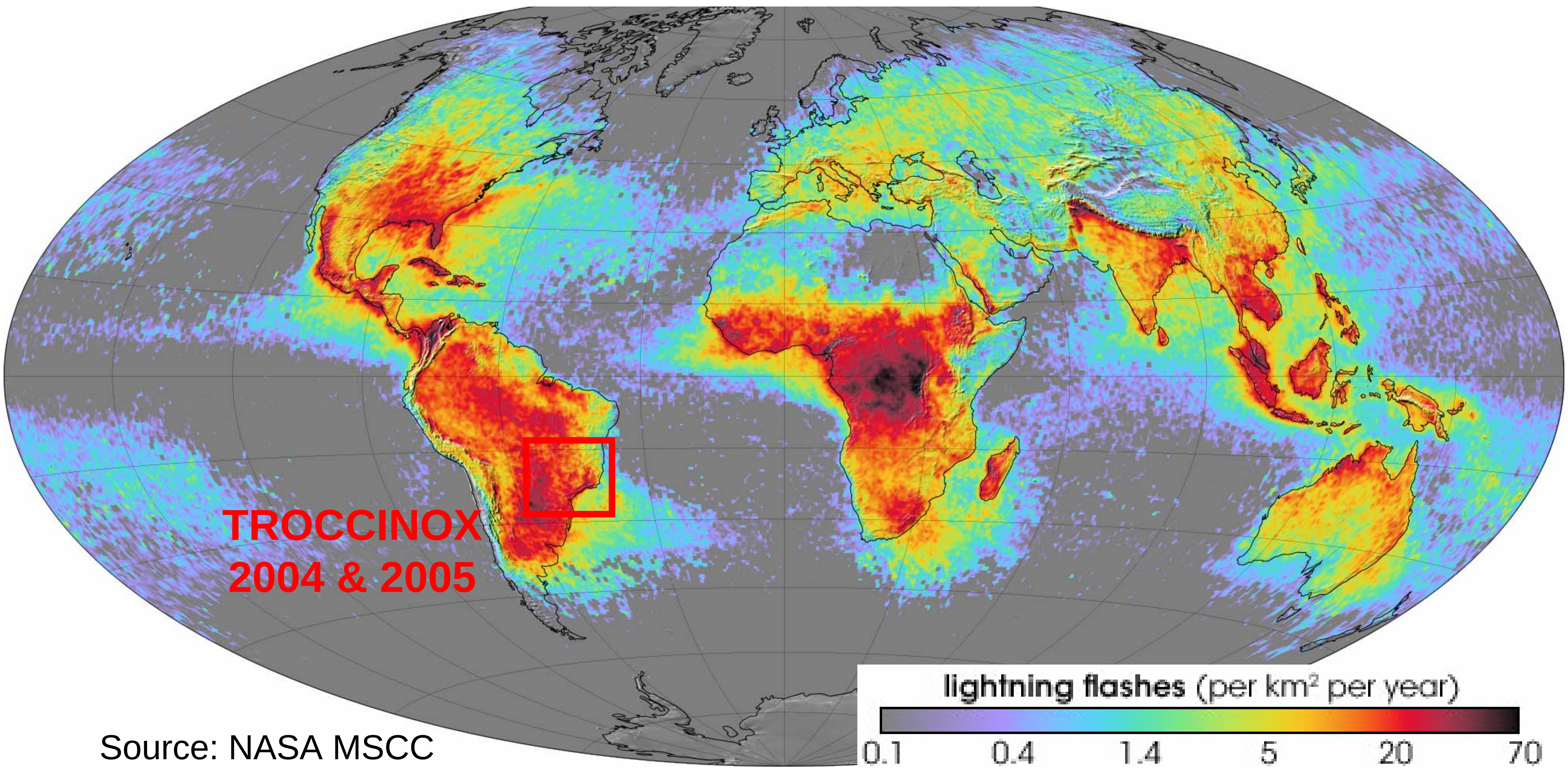
Ulrich Schumann, Heidi Huntrieser and Volker Grewe

DLR – Institute of Atmospheric Physics

Oberpfaffenhofen, Germany

Annual mean lightning flash frequency density

OTD: Optical Transient Detector (1995-1999); LIS: Lightning Imaging Sensor (1998-today)



Source: NASA MSCC
Christian et al. (2003)
Christian and Petersen (2005)

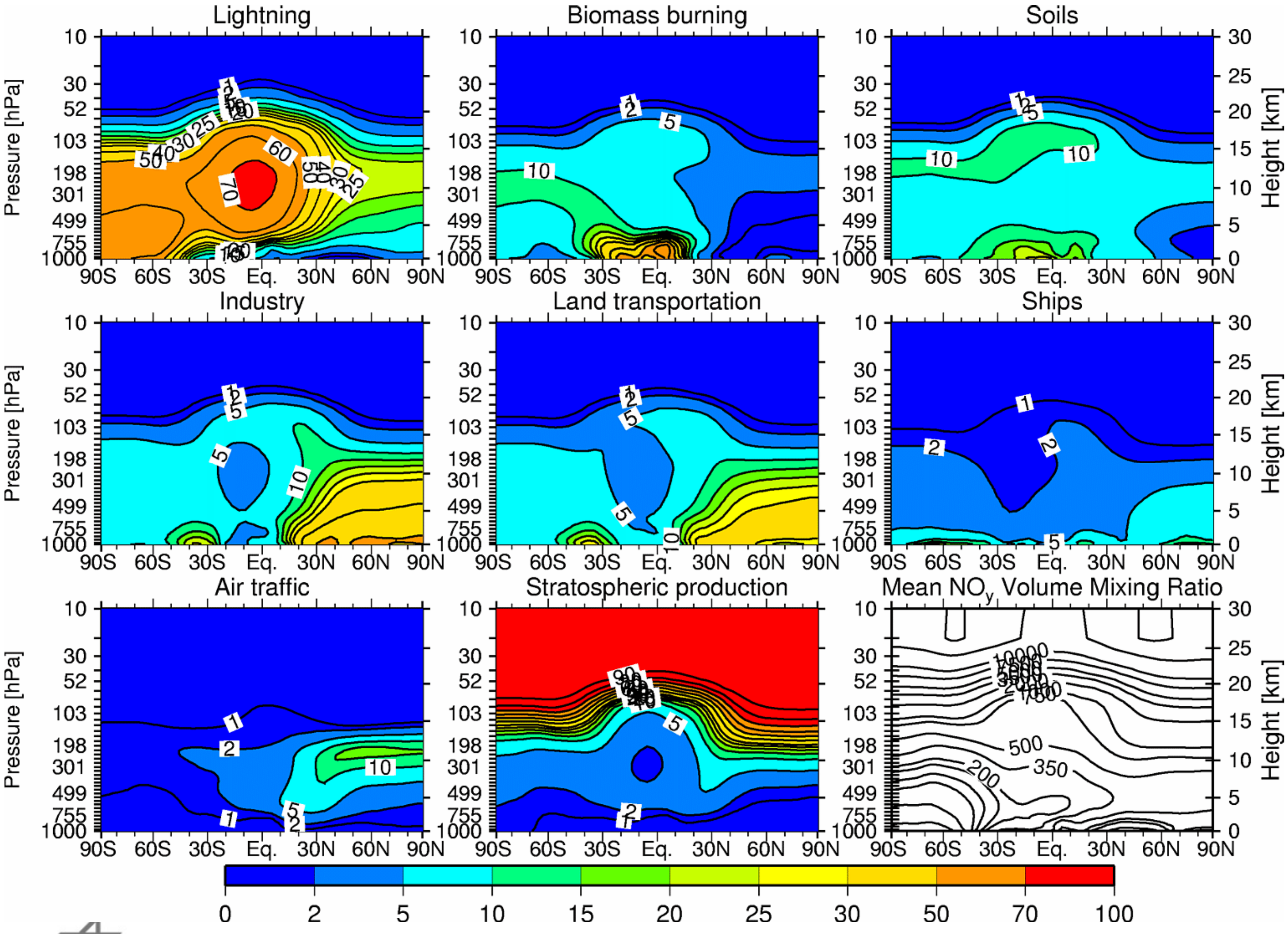
Global mean flash frequency
44±5 s^{-1}

Some previous assessments of the global annual mass source of lightning induced nitrogen oxides (LNOx)

Reference	Flash rate, s^{-1}	LNO_x source rate in N mass, Tg a^{-1}
Tuck (1976)	500	4
Chameides et al. (1977)	400	30-40
IPCC (1992)		2-20
Lawrence et al. (1995)	100	2 (1-8)
WMO (1999)		5 (2-20)
IPCC (2001)		5 (2-13)
Huntrieser et al. (2002)	65	3 (1-20)
IPCC (2007), Boersma et al. (2005)		3.5 (1.1-6.4)
Present estimate	44	5±3 (2-8)

LNOx contributes only about 10 % to total nitrogen mass emissions (≅ 50 Tg a^{-1}), but:

LNOx: >60% of NO_y, and > 30 % of O_3 in Tropics given a global LNOx source of 5 Tg a^{-1}



NOy contributions from various sources

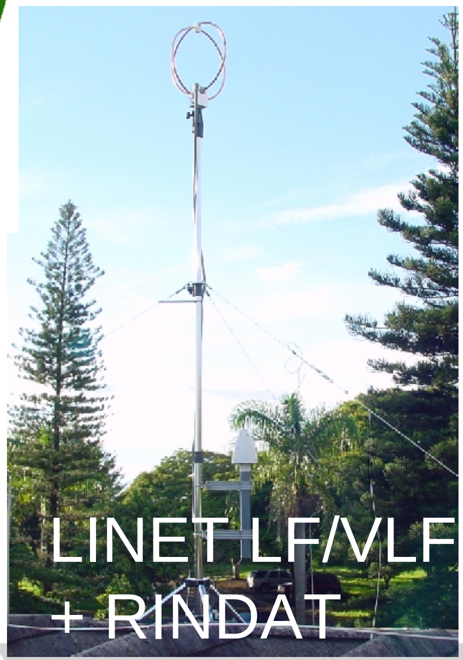
computed with climate-chemistry model E39/C, for the period 1990-1999

(Grewe, 2007)

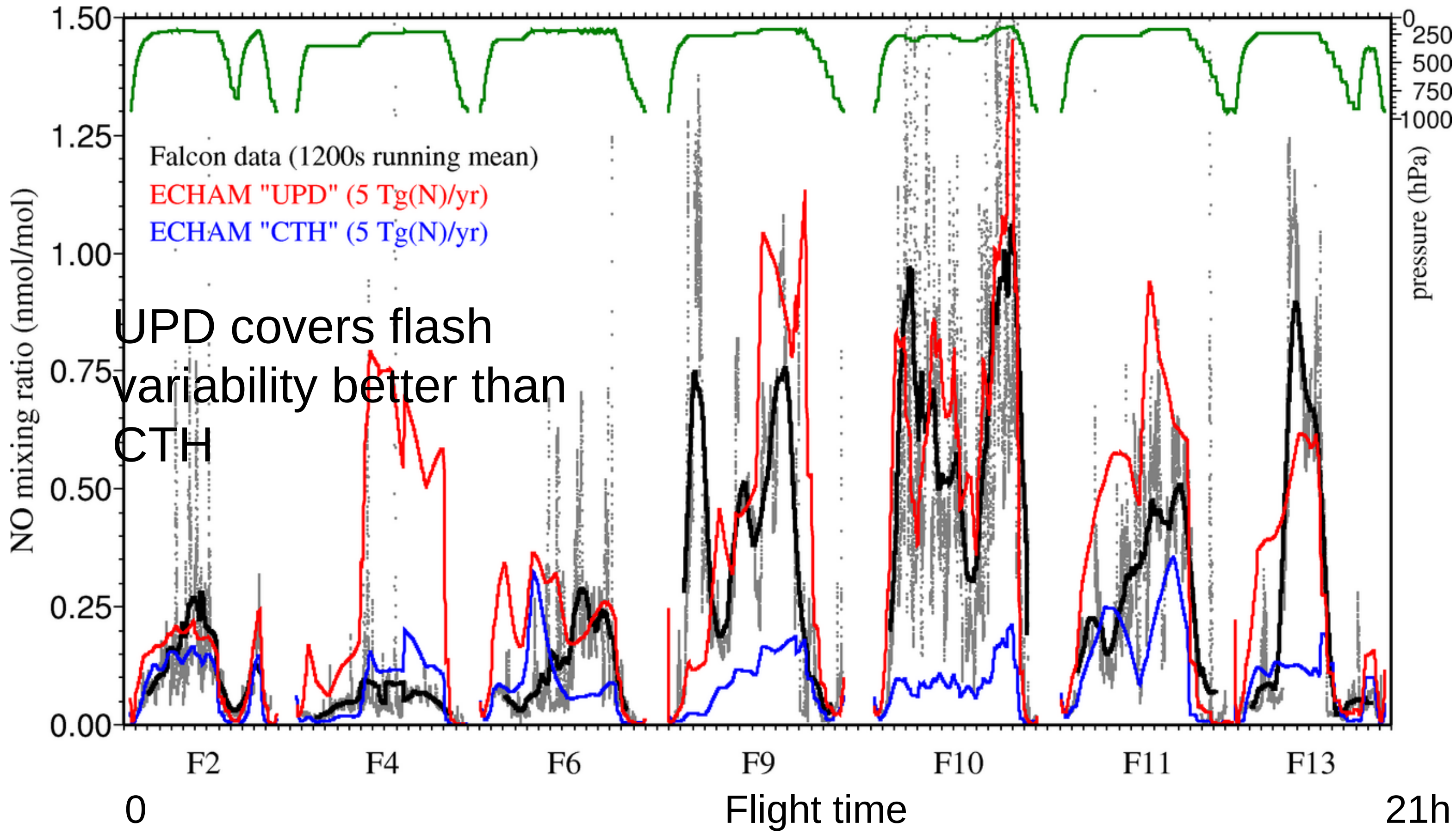
Estimates of global lightning induced nitrogen oxides (LNOx), in nitrogen mass per year

Method	Typical references	Range, Tg/a
Flash extrapolation: S = Production per flash × global flash rate	Tuck (1976) Lawrence et al. (1995) Beierle et al. (2006), etc.	0.6-14
Storm extrapolation: S = Production per thunderstorm × global thunderstorm rate	Chameides et al. (1987) Ridley et al. (1996, 2004) Huntrieser et al. (1998, 2007) Skamarock et al. (2004)	1-25
Model fit: S in global chemical transport model fitted to observations	Levy et al. (1996) Martin et al. (2002) Tie et al. (2002) Staudt et al. (2003) Boersma et al. (2005) Müller and Stavrakou (2005) Schumann et al. (2006) Martin et al. (2007) Sauvage et al. (2007)	2-8

TROCCINOX
45-50°W, 20-25°S
Feb 2004 + Feb 2005

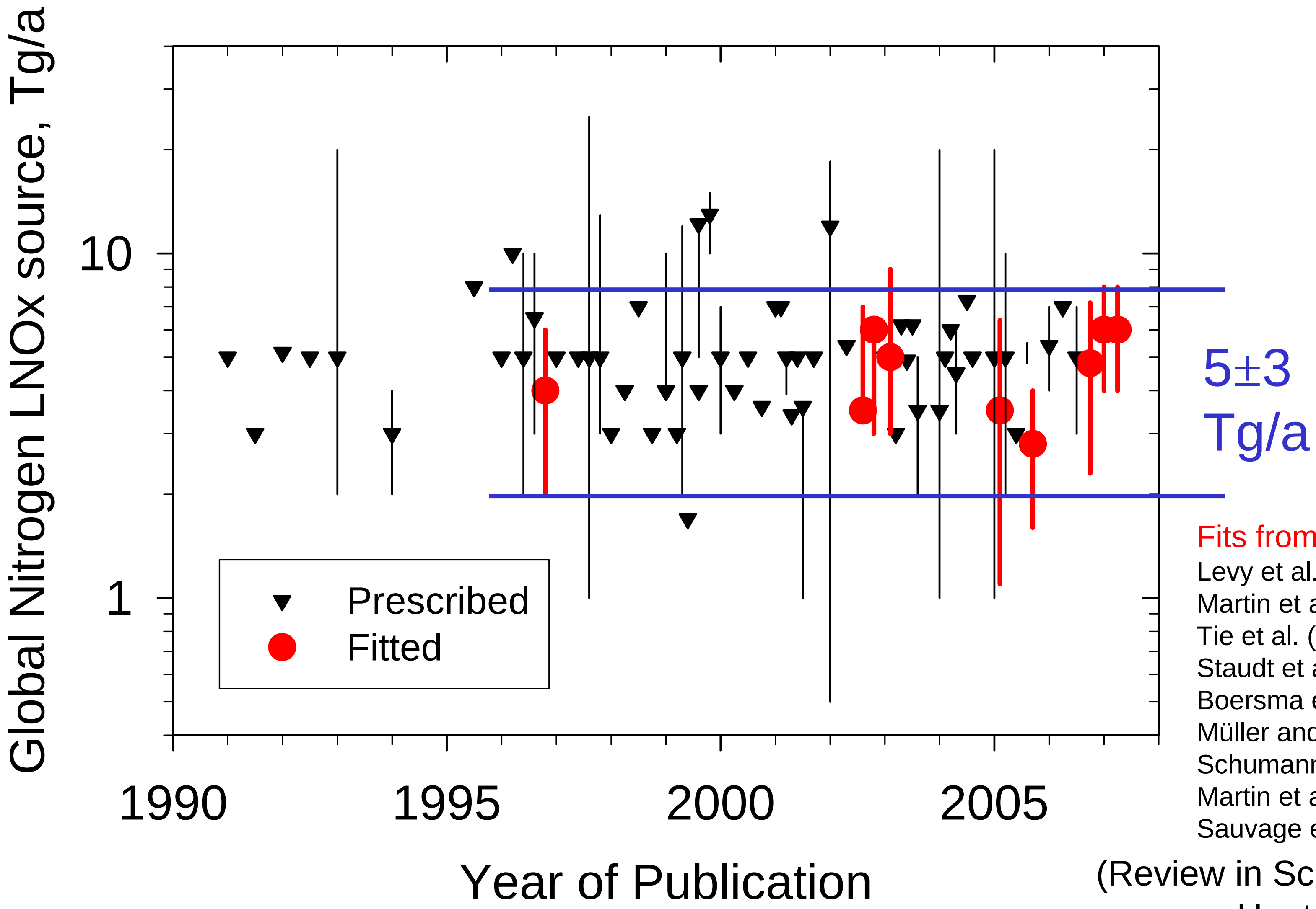


ECHAM5/MESSy model fit to TROCCINOX data, lightning parameterization: updraft speed (UPD) and cloud top height (CTH)



(Kurz, 2005; Schumann et al., 2006)

LNOx source rates assumed or from fitting global models to observations



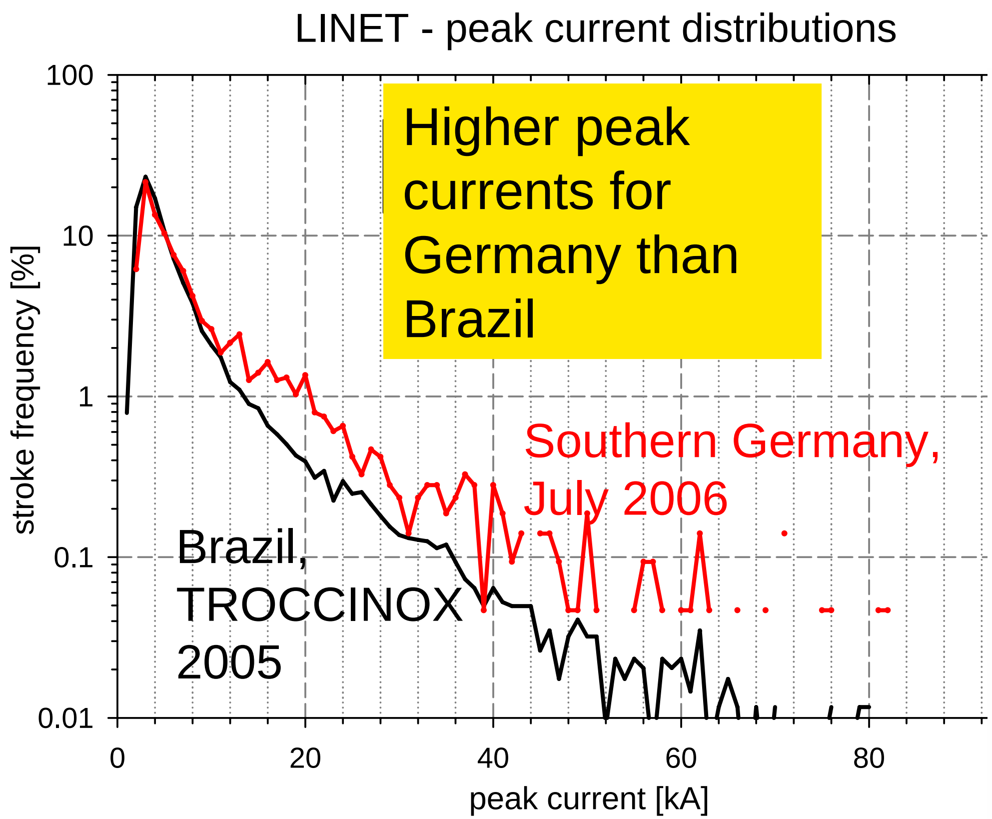
Fits from
Levy et al. (1996)
Martin et al. (2002)
Tie et al. (2002)
Staudt et al. (2003)
Boersma et al. (2005)
Müller and Stavrakou (2005)
Schumann et al. (2006)
Martin et al. (2007)
Sauvage et al. (2007)

(Review in Schumann and Huntrieser, 2007)

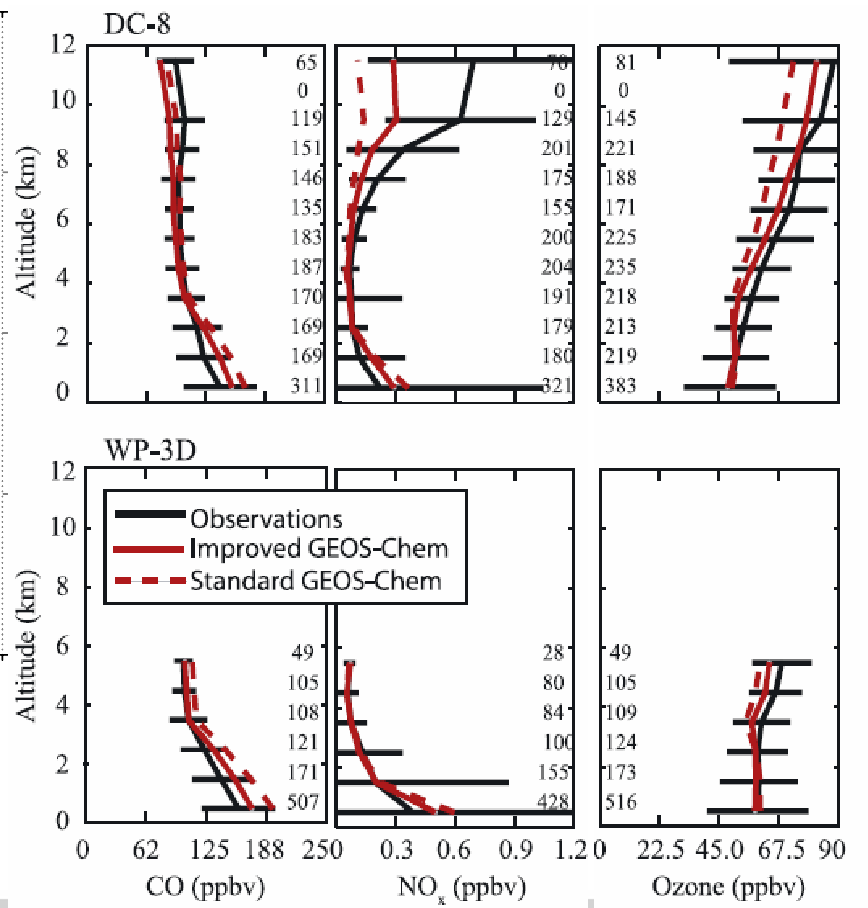
Higher LNOx/flash at mid-latitudes compared to tropics?

(Martin et al., 2006; Hudman et al., 2007)

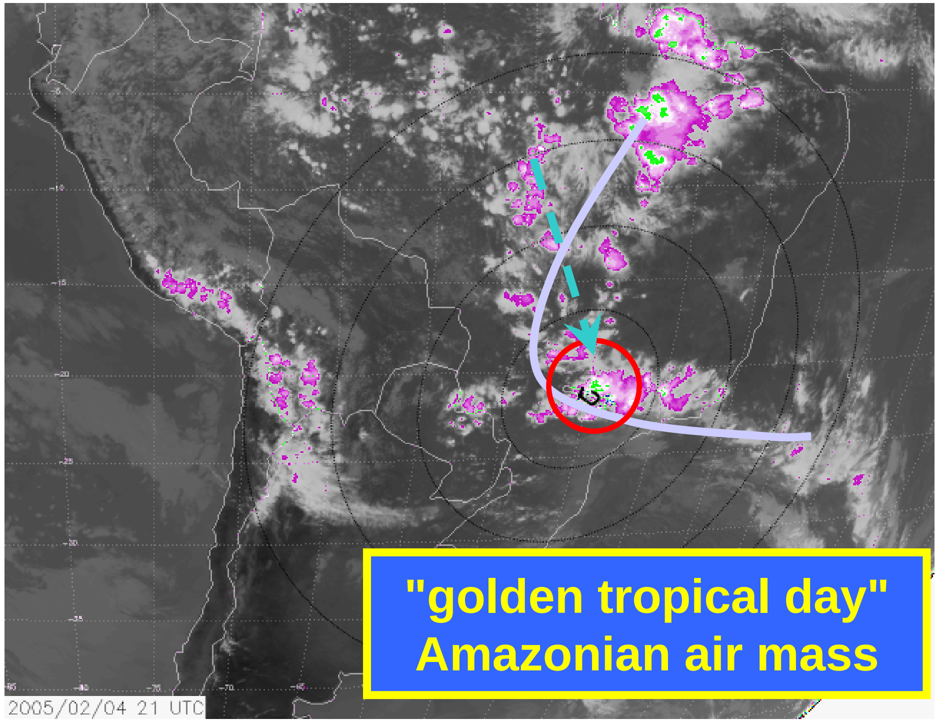
(Huntrieser et al., EGU 2006)

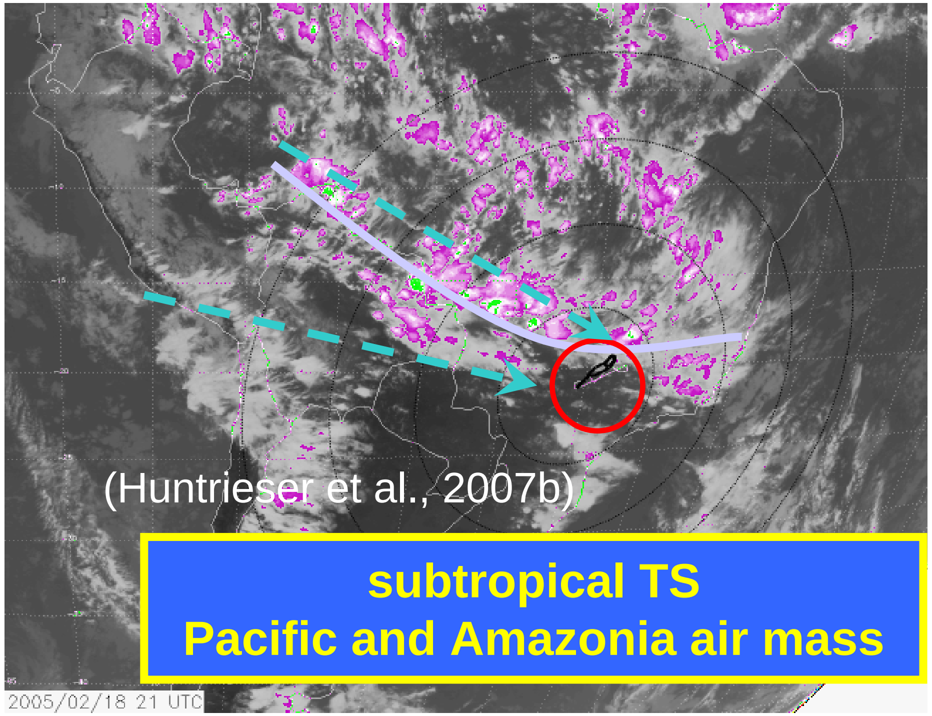


Higher LNOx/flash to fit ICARTT:
ML: 500 mol, T: 125 mol/flash



Selected thunderstorms: tropical and subtropical air masses

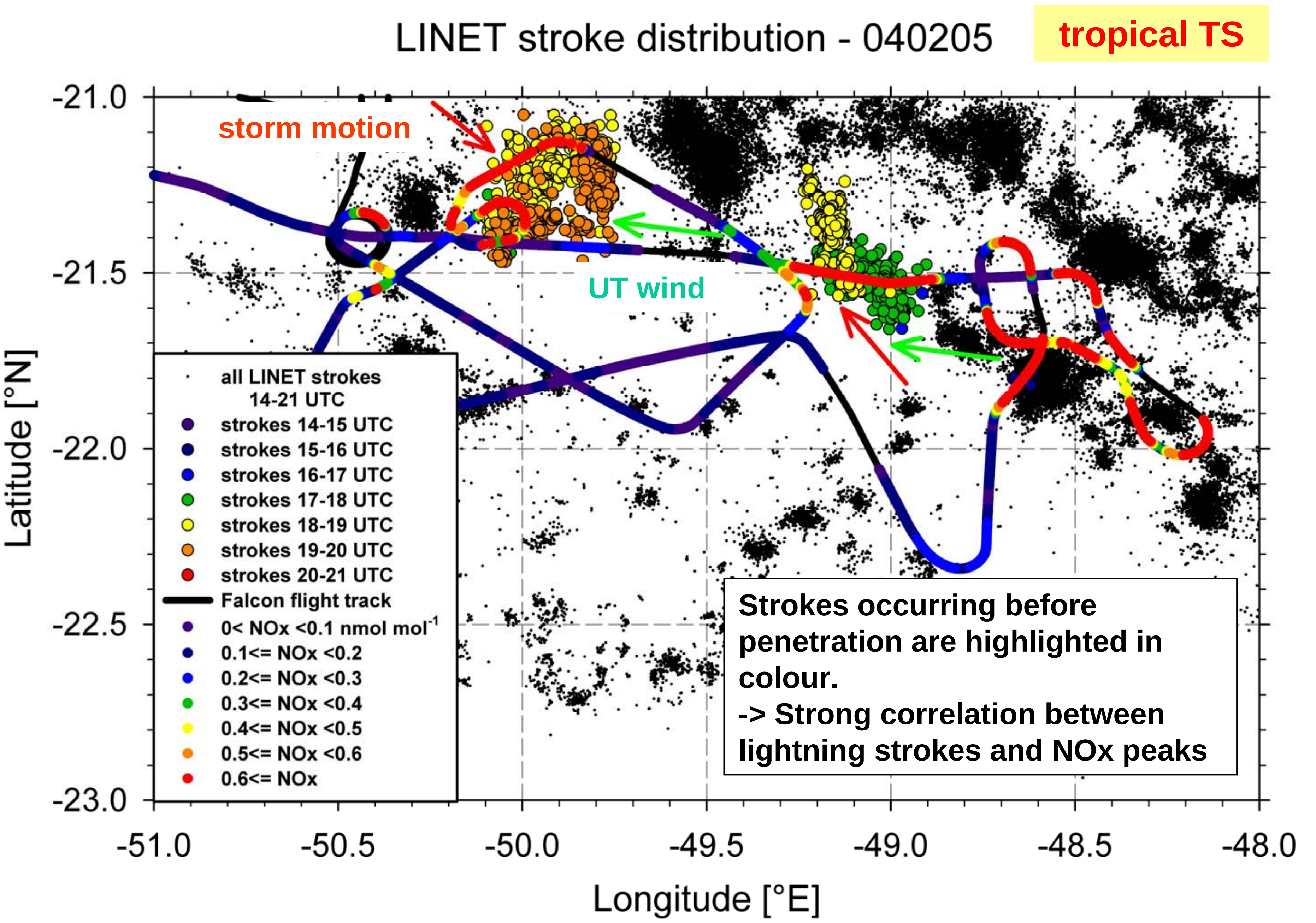


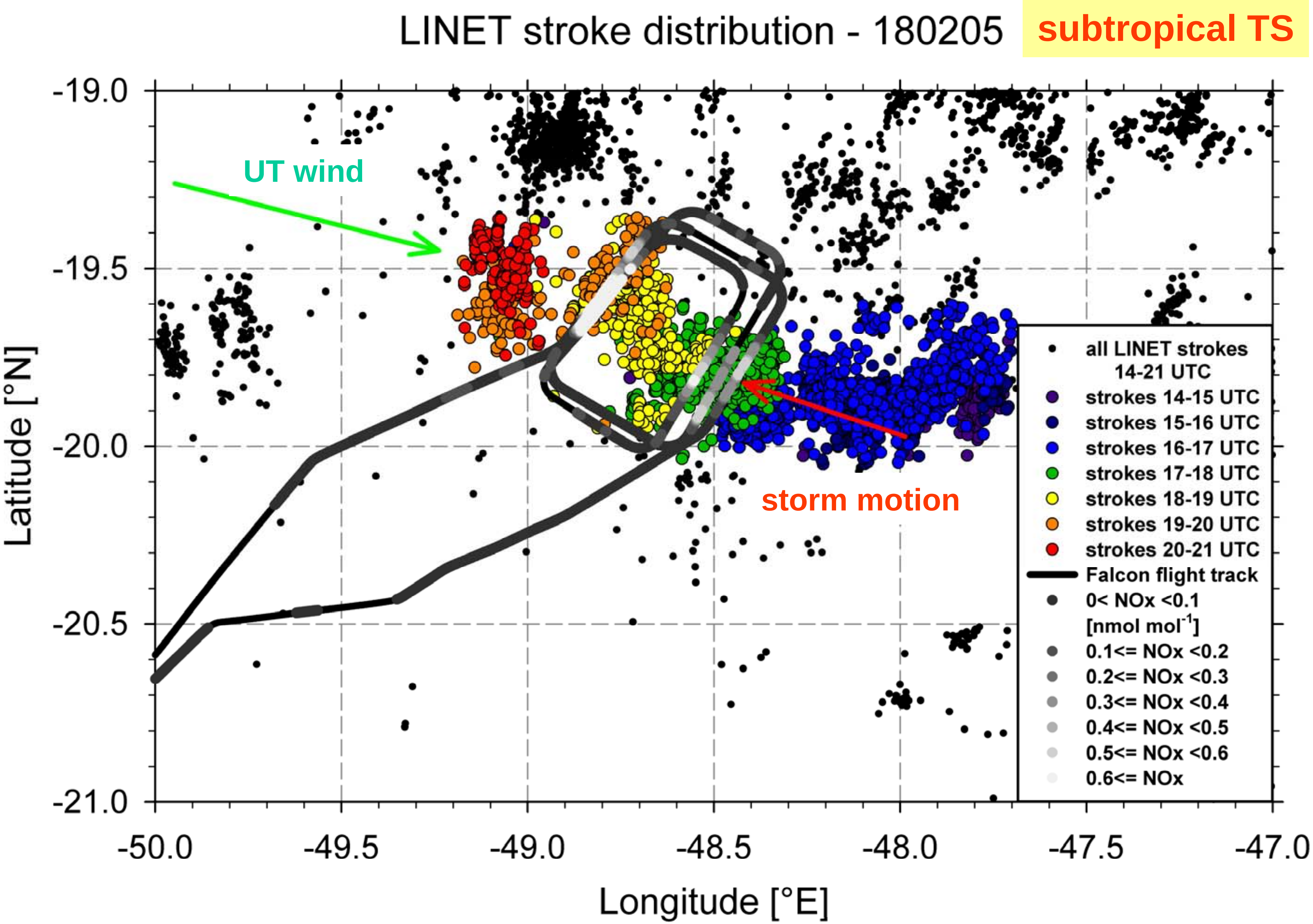


4 Feb 2005, 21 UTC

18 Feb 2005, 21 UTC

LINET, VLF (5-200 kHz) lightning detection (Betz et al., 2004), 6 stations




LINET stroke distribution - 180205
subtropical TS
UT wind
storm motion
-19.0
-19.5
-20.0
-20.5
-21.0
Latitude [°N]
-50.0
-49.5
-49.0
-48.5
-48.0
-47.5
-47.0
Longitude [°E]
all LINET strokes 14-21 UTC
strokes 14-15 UTC
strokes 15-16 UTC
strokes 16-17 UTC
strokes 17-18 UTC
strokes 18-19 UTC
strokes 19-20 UTC
strokes 20-21 UTC
Falcon flight track
0< NOx <0.1 [nmol mol-1]
0.1<= NOx <0.2
0.2<= NOx <0.3
0.3<= NOx <0.4
0.4<= NOx <0.5
0.5<= NOx <0.6
0.6<= NOx

LNOx N mass/flash from observations

Input:

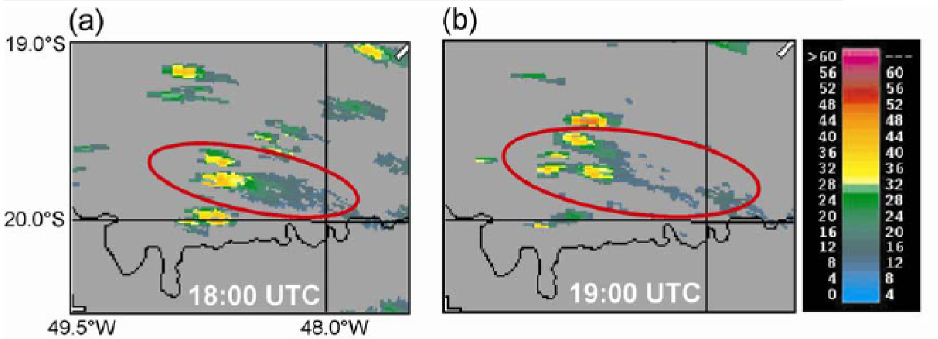
- Falcon: NO_x, u, v, <12 km
- Geophysica: NOx above 12 km altitude
- Radar and FLEXPART: plume width
- LINET: flash #, x, y, I
- LIS: LINET->globe

tropical thunderstorm:
~1 kg (70 mol) per LIS flash

subtropical thunderstorm:
~2-3 kg per LIS flash

for the 2 case studies

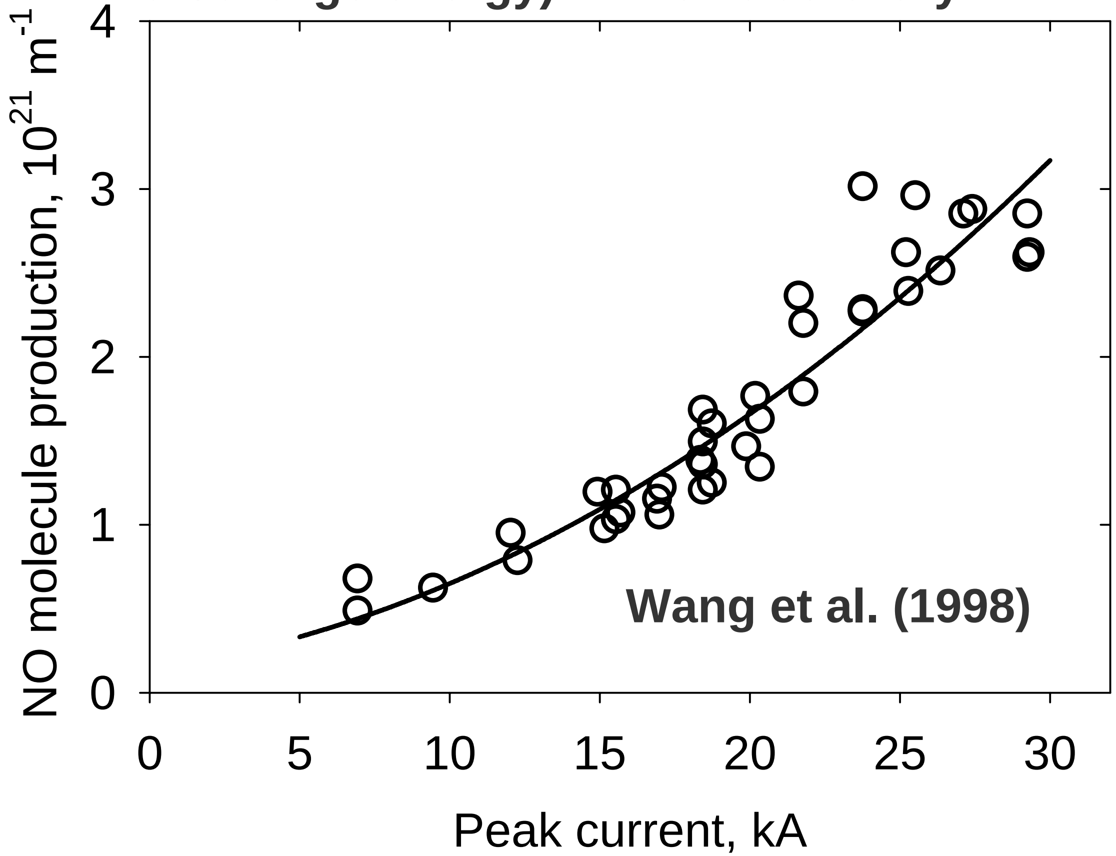
Details: Huntrieser et al. (2007b)



Radar example, 18 Feb 05

LNOx production per flash and unit length

LNOx controlled by peak current (not discharge energy) in the Laboratory:



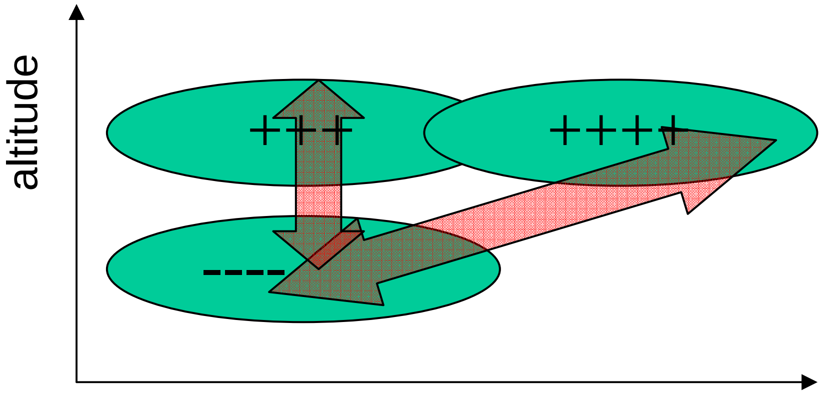
For given peak currents and LNOx amount -> Length:

tropical storm:
~44 km / flash

subtropical storm:
~160 km / flash

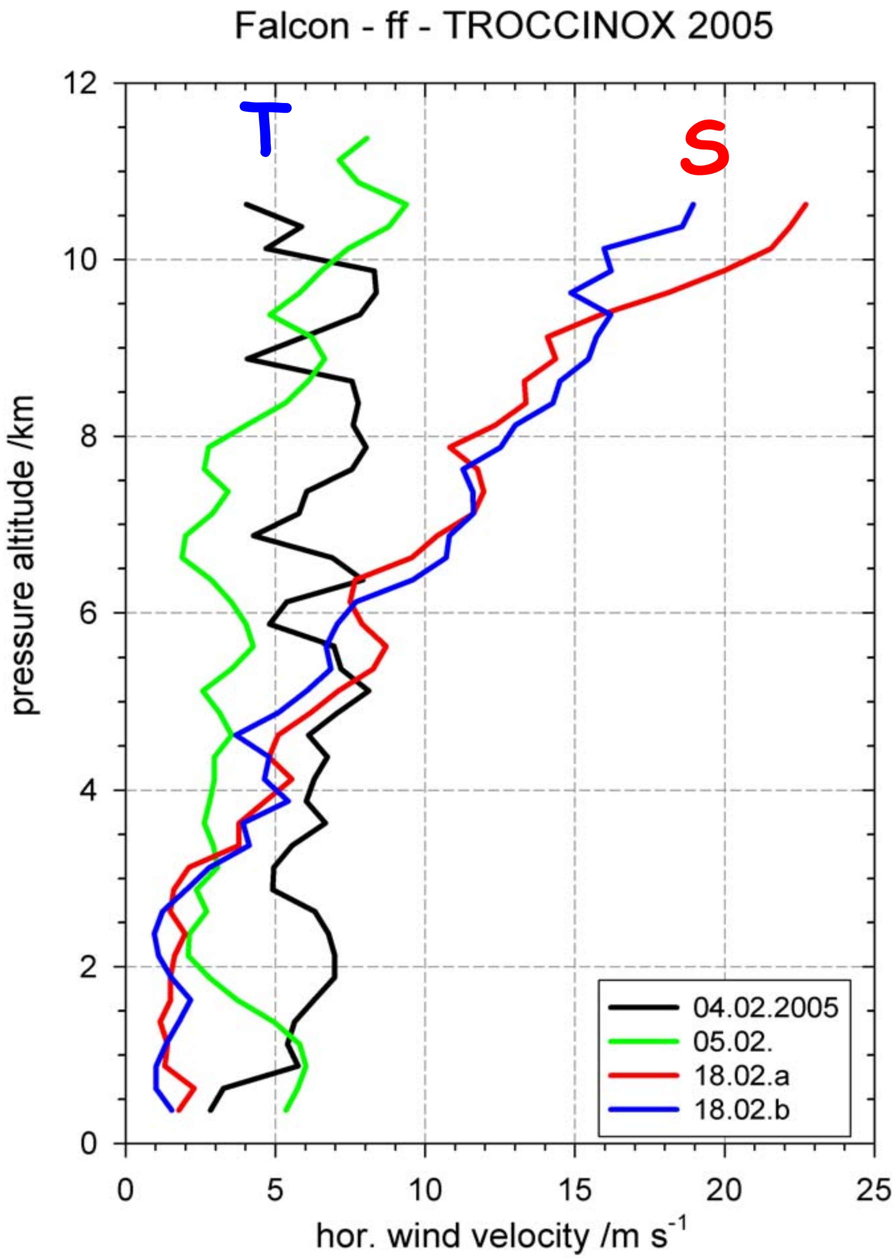
High values?
Shear effect?
fractal structure?
Real flash more productive than laboratory spark?

The shear in subtropical (and mid-latitude) thunderstorms is larger than in the tropical cases

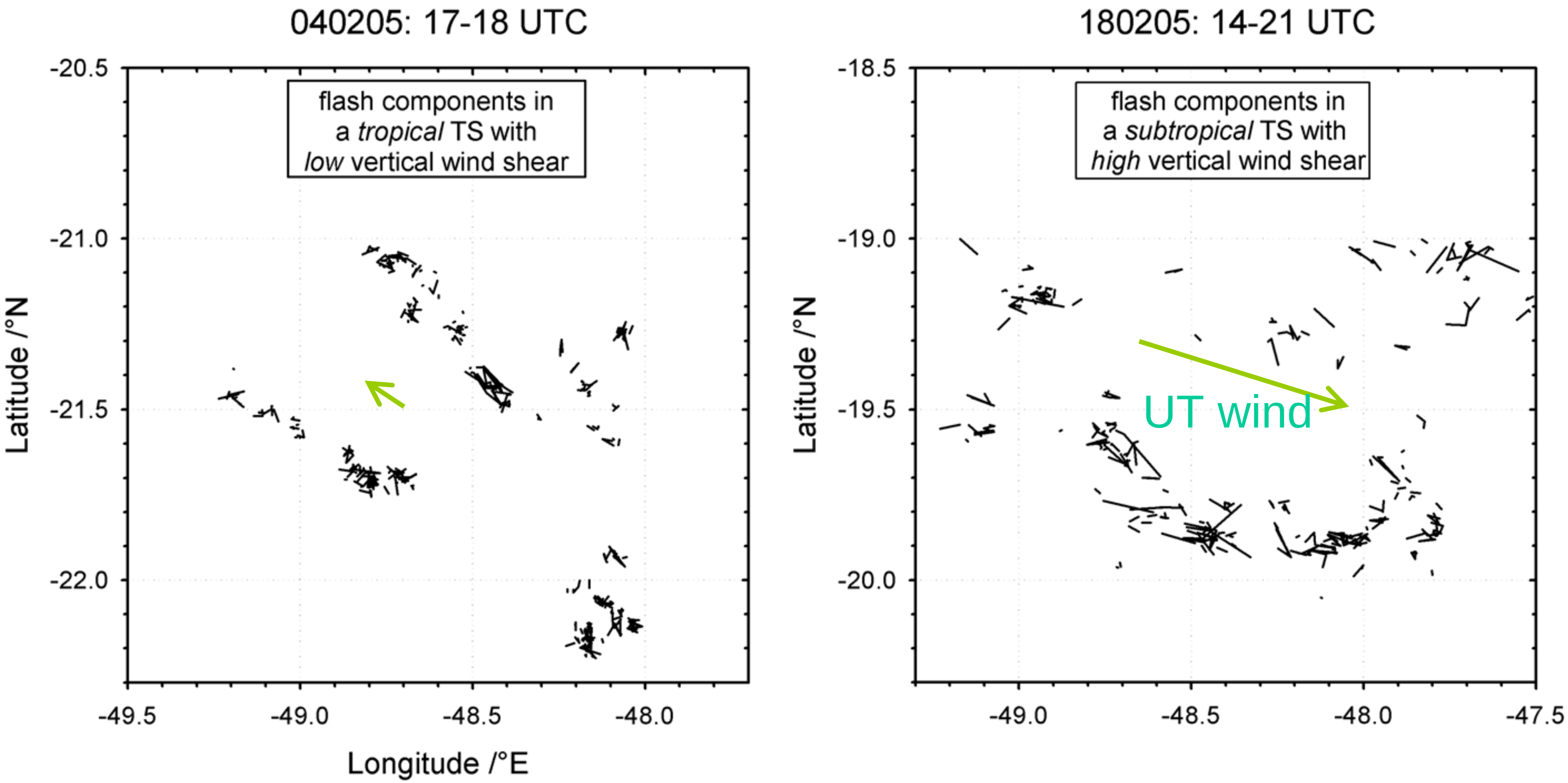


Wind shear causes spatial separation of charged regions ->

longer flashes,
possibly also larger peak currents,
higher NOx production per flash!



Flash component observations show: flashes in the ST storm with shear are ~2 x longer than the tropical ones



Flash component: VLF sources along a flash within 1 s,
Data derived from RINDAT VLF/LF lightning observations

TROCCINOX-publ. in ACP Special Sect.:

Schumann, U., and H. Huntrieser, 2007:
The global lightning-induced nitrogen oxides source,
Atmos. Chem. Phys., *7*, 3823-3907,

Huntrieser, H., H. Schlager, A. Roiger, M. Lichtenstern, U. Schumann, C. Kurz, D. Brunner, C. Schwierz, A. Richter, and A. Stohl, 2007:
Lightning-produced NOx over Brazil during TROCCINOX: Airborne measurements in tropical and subtropical thunderstorms and the importance of mesoscale convective systems,
Atmos. Chem. Phys., *7*, 2987-3013,

Huntrieser, H., U. Schumann, H. Schlager, H. Höller, A. Giez, H.-D. Betz, D. Brunner, C. Forster, O. Pinto Jr., and R. Calheiros, 2007:
Lightning activity in Brazilian thunderstorms during TROCCINOX:
implicatons for NOx production,
Atmos. Chem. Phys. Discuss., *7*, 14813-14894.

Conclusions

- **Global LNOx N-source rate 5 ± 3 Tg/a**

- **Subtropical and midlatitude flashes seem to produce 2-3 times more NOx per flash**
- **because of stronger wind shear (NEW!)**

Future:

- **Further coordinated flash/NOx observations needed**
- **Include shear effect into account models**
- **Run models with highest possible (cloud scale?) resolution**
- **Perform long-term CTM-runs with high resolution meteorological fields for 1990-2007 and determine the model parameters such that the model results best fit the many existing NOx, O3, CO, … observations.**